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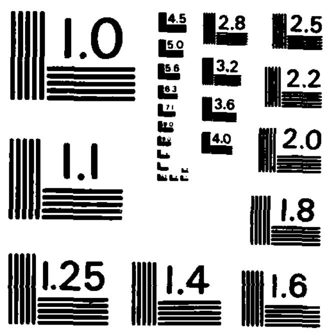

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APPLICATIONS OF ARTIFICIAL INTELLIGENCE TO THE STRATEGIC DEFENSE INITIATIVE'S BATTLE MANAGEMENT/COMMAND AND CONTROL OBJECTIVE

THESIS

Lorraine M. Gozzo
Captain, USAF

AFIT/GSM/LSY/85S-13

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DEPARTMENT OF THE AIR FORCE
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AFIT/GSM/LSY/85S-13

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APPLICATIONS OF ARTIFICIAL INTELLIGENCE

TO THE

STRATEGIC DEFENSE INITIATIVE'S

BATTLE MANAGEMENT/COMMAND AND CONTROL OBJECTIVE

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Systems Management

Lorraine M. Gozzo, B.S.

Captain, USAF

September 1985

Approved for public release; distribution unlimited

Preface

The purpose of this study was to evaluate artificial intelligence techniques and determine their applicability to the Battle Management/Command, control and communications objective of the Strategic Defense Initiative. Directing research and development efforts in specific areas will lead to faster development of useful artificial intelligence techniques.

An extensive literature review along with personal interviews were the sources of data for this effort. Since this is very subjective, the reader is reminded that the results are not to be taken as concrete facts. Results indicated that it was inevitable that various artificial intelligence techniques will be used in the Strategic Defense Initiative's Battle Management/Command, control and communications issue.

I would like to thank my faculty advisor, Major Ron Hitzelberger for his patience and assistance during the many revisions of this thesis. Thanks also go to my reader, Capt Stephen Cross, for his assistance and valuable feedback.

Lorraine M. Gozzo

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Abstract

This ~~investigation~~ thesis determined the applicability of various artificial intelligence techniques to the Battle Management/Command, control and communications (BM/C3) objective of the Strategic Defense Initiative.

This analysis was accomplished by an extensive literature review followed by personal interviews with members of various organizations within the Department of Defense (DOD). Interviews were limited to people in the DOD because of their anticipated willingness to provide information versus non-DOD people. The results obtained are an accumulation of opinions and perceptions and are not to be taken as concrete facts.

Results indicated that the artificial intelligence techniques that would be most beneficial to the Battle Management/Command, control and communications issue are expert systems, knowledge-based systems, automatic programming and natural language processing. Areas of BM/C3 where these techniques were considered to be of most benefit include event classification and discrimination, resource allocation, sensor allocation, real-time response capability, data processing, surveillance and intelligence, electronic equipment maintenance, software generation and increased testability of BM/C3 systems. Keywords: [illegible] Strategic [illegible]

APPLICATIONS OF ARTIFICIAL INTELLIGENCE TO THE STRATEGIC DEFENSE INITIATIVE'S BATTLE MANAGEMENT/COMMAND AND CONTROL OBJECTIVE

I. Introduction

Problem Statement

As our command and control strategies increase in complexity, the technology required to carry them out will also increase. Advances in Artificial Intelligence (AI), in computer hardware and software and in signal processing will aid in the development of the complex command and control systems needed.

Artificial Intelligence is a new and rapidly evolving field where research efforts are continually striving for state-of-the-art technology. Many applications of AI techniques can help the Department of Defense in reaching its goals in the Strategic Defense Initiative (SDI). The SDI is a huge research effort aimed at developing technologies that can provide an effective defense against ballistic missiles. Issues that the SDI encompasses are the ballistic missile defense environment, surveillance, acquisition and tracking, intercept and target destruction, survivability, and offensive responses.

The particular area of the Strategic Defense Initiative researched here for possible AI applications is the Battle Management/Command and Control technology issue.

The purpose of battle management is to make the best use of defense resources. It is a data processing and communication system that includes command, control and communication facilities. Its tasks include situation monitoring, resource accounting, resource allocation, and reporting (20:9). Sensors survey the field of battle and collect data. The raw data is then filtered to reduce the volume. The resources (i.e. sensors and weapons) are assigned to certain sectors or targets of interest. Resource allocation involves selecting a course of action that will optimize some objective, for example, the number of targets destroyed. Finally, the data must be reported to authorities external to the defense system so that any hostile developments can be inferred, a defense condition level determined and appropriate action taken.

Command and Control (C2) comprises many related technology areas such as C3 (command, control and communications), C3I (command, control, communications and intelligence), and C4I (command, control, communications, computers and intelligence) (36:23). To illustrate some of the functions that command and control systems have to perform consider an Air Force C3I system. The function of an Air Force C3I system is to perform all elements of

command and control and decision making from force direction to logistics support, including air battle management, ground target surveillance, strike control, electronic warfare, information and intelligence collection, and sensor management (11:256). It is a complex mix of equipment, people, and organizations that operate command facilities, communications systems, data processing systems, and collectors and sensors. Hereafter, reference to the SDI's Battle Management/Command, control and communications program will be referred to as BM/C3.

Background

The Strategic Defense Initiative (SDI) is a multi-billion dollar research and development program aimed at exploiting emerging technologies. It is a very popular and controversial topic that newspapers report on daily and is more commonly known as "STAR WARS".

"The immediate goal of the Strategic Defense Initiative is to conduct research on technologies required to intercept ballistic missiles after they have been launched to prevent them from hitting their targets" (47:108). In the long run the SDI is to explore the means to defend military targets as well as civilian populations in the US and in allied countries.

In the coming years, more than 50% of all SDI funding will go toward work not directly involved in the weapons part of the program. A major portion of the nonweapon work

will be directed at battle management (46:53). This critical technology issue is expected to take years of research (20:11). According to Lt Gen James A. Abrahamson, director of the SDI organization heading up implementation of the new strategy, there are serious questions and concerns with SDI's battle management, especially with regard to architecture, software structure and the huge data-processing problem (47:118). "The key technology areas under battle management/C3 are critical circuit technology, situation analysis and human decisions, protocols for internetting multitier C3 links, battle management algorithms and communications technology" (2:36).

The Department of Defense plans to develop complex command and control systems while allowing the systems' battle management (BM) and command, control, and communications (C3) component architecture to incorporate future improvements without having to disrupt all the software concepts (47:118). Many individual research studies, in the $10M to $12M range, will give industry freedom to identify key tradeoffs, establish new architecture concepts, and surpass state-of-the-art ideas. According to the Electronic Industries Association, the C3 systems being developed for the SDI will be three to five times more complex than any C3 system in operation today (2:36). The computer programs necessary to run an efficient battle management program will require nearly ten million lines of code (2:36, 20:10).

Advancement of technology in computer hardware and software and signal processing will eventually allow the realization of the complex command and control systems that the Department of Defense needs. One area of research that can aid in this technology advancement is Artificial Intelligence.

Artificial Intelligence (AI) is a popular research topic with the Department of Defense. It is a fairly new and expanding field of study that has the potential to be a very powerful tool. AI comprises a group of related technologies including natural language processing, intelligent retrieval from data bases, expert consulting systems, theorem proving, robotics, automatic programming, perception, cognition, learning, and knowledge-based expert systems (35:2-7).

The theme of a recent Air Force Association symposium held in Colorado Springs, CO was "Military Imperatives in Space". Dr Robert S. Cooper, Assistant Secretary of Defense (Research and Technology) and Director of the Advanced Research Projects Agency (DARPA), spoke at the meeting on the topic of AI. According to Dr. Cooper,

> Artificial Intelligence (AI), meaning computational processes that incorporate associative reasoning to resemble the thought processes of the human mind, could have a revolutionary impact on future military space operations. AI might make possible satellites that can function for months and years without human intervention. (45:97)

The Department of Defense would benefit from an investigation of possible AI techniques and applications that could aid Battle Management/Command and Control. Research needs to begin now to explore and define the future role of AI in the SDI Battle Management/Command and Control program so that near-term applications can be channeled in directions that lead to the greatest payoff.

Research Objectives

The research objectives of this study are to:

1. Survey the state-of-the-art of command and control technology and identify technology that could benefit from the use of Artificial Intelligence.
2. Survey the state-of-the-art of Artificial Intelligence techniques and identify their applicability to the SDI's Battle Management/Command, control and communications.
3. Determine, using specified criteria (such as development time, costs, risks), a rank-ordering of AI applications that could benefit the Battle Management/Command, control and communications objective of the Strategic Defense Initiative.
4. Postulate the potential benefits of using AI in the SDI's BM/C3 program.
5. Recommend various AI techniques to incorporate into the SDI's BM/C3 program.

Scope of the Research

This research effort is focused on the Strategic Defense Initiative's Battle Management/Command and Control objective. Various artificial intelligence techniques and applications will be researched to determine which may be useful to the SDI. Advances in Command and Control technology will be researched to determine appropriateness to AI. The results obtained will be an accumulation of opinions and perceptions of various experts in the fields of AI and C3. Therefore, the results are not to be taken as concrete facts.

The primary limitation of the research is that it will be limited to research of unclassified information.

II. Literature Review

The information contained in this chapter is the result of an extensive literature review on Command and Control, the Strategic Defense Initiative and Artificial Intelligence. It is presented to increase the reader's understanding in these areas and provide a foundation for further research and discussion.

Introduction

Command and Control can be thought of as a system that brings individual pieces of a defense system together into a coherent overall structure (10:179).

The official Department of Defense definition of command and control is as follows:

> Command and Control: The exercise of authority and direction by a properly designated commander over assigned forces in the establishment of a mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures which are employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. (21:76-7)

Command and Control (C2) encompasses many related technologies including Command, control and communications (C3), Command, control, communications and intelligence (C3I), Command, control, communications, and computers (C4), and Command, control, communications, intelligence, and interoperability (C3I2)(36:23). The C2 and C3 terms are of

primary interest to this research effort and are sometimes used interchangeably.

U.S. Command and Control Structure

A brief history of how the United States Command and Control structure has evolved follows.

The start of the nuclear age in 1945 did not create big problems for command and control. The small number of nuclear weapons that existed made the nuclear force easy to manage.

However, one problem the military experienced was the physical possession of the weapons. The Atomic Energy Act of 1946 created the Atomic Energy Commission (AEC) and set up a coordinating link between the AEC and the military (10:180). All atomic weapons were under the immediate control of AEC guards. Only under direct presidential orders would these weapons be turned over to the military for matching with delivery vehicles.

The military argued that it could not carry out its mandated assignments unless it had prompt access to these weapons. By 1956 the entire nuclear stockpile had been turned over to the military.

Between 1955 and 1960, the development of nuclear forces was in a critical period. Soviet nuclear capability was growing and the United States had to plan for a Soviet attack and start developing forces that could go to war on a moment's notice.

The American nuclear strategy of the day required three things of the command structure: (1) a large nuclear force, (2) an excellent warning system, and (3) a streamlined command structure. A hardened command system was not required, and only rudimentary protective measures were taken.

> The theory behind the "soft" design for command and control was that the purpose of all these systems was to get warning in order to launch a nuclear attack. In the 1950's there were no plans to fight a limited or controlled nuclear war . . . . The assumption in the U.S. was that the military command posts had no function after they launched their missiles (10:188).

The American Command system underwent major changes in the 1960's. A new emphasis on limitation in attack resulted in new requirements. It required survivable nuclear forces, a survivable national command authority (to make decisions during a war), and survivable communications between the command authority and the nuclear forces. All of these revisions are features of flexible response.

The main problem in 1961 was not associated with designing a new command and control system for flexible response but to take the large existing command system and adapt it to the new requirements.

One major change was the decentralized command system. This structure prevented the enemy from disabling the entire command system with a single weapon aimed at the presidential command center.

Many factors have shaped the command system from the late 1960's to the present. These include:

1. Environmental changes---especially the expanding Soviet threat
2. Vertical integration of warning and intelligence systems with the nuclear forces
3. Structural complexity
4. Erosion of the common carrier communications network
5. Greater than anticipated vulnerability of the system's pieces to blast, radiation, EMP [electromagnetic pulse], and shock (10:212-3)

In the 1960's the Soviet ICBM force was small and extremely unreliable. Although the U.S. had more missiles and might have "won" a nuclear war in the early 1960's, the consequences for the U.S. would have been catastrophic. If even a few of the Soviet ICBM's hit the U.S., fatalities would have been in the millions (10:213). The small Soviet force has evolved into a large force today. The size of both the U.S. and Soviet arsenals today causes each side to search for the other's weak links. These weak links appear more and more to be the command structures that control the forces.

"With the inception of the North American Aerospace Defense Command in 1957, a major step was taken to vertically integrate the U.S.'s nuclear weapons with a specialized intelligence and warning management" (10:7). A major result of this was the need to have wartime organizations operating in peacetime 24 hours a day. They had to be ready to go with only a moment's notice. Some improvements that resulted from the vertically integrated

warning and force system include: increased warning time of attack, improved safety of the bomber force, and better exploitation of intelligence information by NATO tneatre nuclear forces (10:7).

Because command and control systems have become more complex, many communication lines interconnect the commands and numbered armies, air forces, and fleets in a way that inhibits a smooth flow of authority. Sometimes the lines send intelligence information, while other times they relay information on authority and coordination (10:217). The result is a structurally complex command system. Steps must be taken to insure that no breakdowns in this command structure will occur during a full alert situation.

Common carriers are vital to the U.S. command and control. The federal government relies heavily on common carrier communication lines. Tactical warning systems and emergency conference calls of the president and military leaders rely on telephone lines and circuits (10:217). "The only defense communication system independent of the telephone network consists of point-to-point radio links" (10:218). These are only useful in short-range communications. For command and control of nuclear forces, long-range communications are required, and these are obtained by linking the short-range VHF and UHF transmissions with the telephone system.

Over the years, the common carriers have been altered considerably by technological and regulatory changes. The result has been a decline in the connectivity, survivability, and reliability of the single most important defense communications system in the nation (10:217). Efforts are now being directed at replacing the common carrier system with mobile point-to-point radio systems. However, more research is still needed to improve the communications systems.

Command centers, computers, radars, satellites, aircraft, and communication lines have all proven to be more vulnerable than was originally anticipated when these systems were designed (10:219). Certainly, survivable communications and systems are desirable, but care must be taken to allocate resources wisely and decide which satellites should be hardened against blast and which communications should be made redundant.

In addition to ensuring that survivable communications exist, the reliability and flexibility of command and control systems must also be addressed. The degrees of reliability and flexibility needed, and the ability to achieve them, is largely a function of the particular uses and operating environments of the command and control systems.

<u>Flexibility</u>. The rapidly changing nature of the command and control environment and of computer hardware and software technology calls for a great deal of flexibility.

A modular concept for software will be useful for command and control systems (16:26). A modular design consists of many loosely-coupled segments; where any one function is contained within a single segment or module.

Command and control software needs to be designed for flexibility. Algorithms and data may need frequent revisions due to rapidly changing capabilities and the nature of weapon systems and threats. Modular software will greatly reduce reprogramming effort and cost and will reduce the risk of negatively affecting other portions of the software.

Reliability. Command and control systems need to be as effective in combat situations as in peacetime. All the capabilities of a command and control system are worth nothing if the system ceases to function in a combat situation. It is therefore necessary to take every precaution to "harden" the system to ensure the integrity and availability of its knowledge base, models, and hardware.

Hardware reliability. Command and control systems require very reliable and rapid processing of real time data. New hardware advances can improve reliability through the use of "Very High Scale Integrated Circuitry" (VHSIC).

Commercial semi-conductor designs cannot meet the speed, density, and reliability requirements of a command and control system (16:29). The VHSIC program was intiated

in 1980 by the Department of Defense to overcome these technological barriers with more capable chips. The new chips provide more processing capability. The reduction in the number of interconnections among chips increases the reliability. The reduction in size of the integrated circuits allows for built-in testing techniques which can simplify maintenance.

Solid state circuitry is very vulnerable to electromagnetic pulsing (EMP). Most new command and control system programs have set aside funds for protective Faraday shielding at the "box" level (16:29). The larger the "box", the more expensive the shielding. VHSIC will greatly reduce the sizes of these components and thus provide savings in shielding costs.

Evolution of C3I and Space Defense

Space C3I may be thought of as beginning in the time frame of the 1962 Cuban Missile Crisis and the Kennedy flexible response doctrine for nuclear missiles (9:9).

President Kennedy assumed some part of the military command would survive a Soviet nuclear attack and that, as a consequence, a measured and controlled American nuclear weapons response was possible through the use of residual capabilities.

Because only a limited capability existed to provide early warning and assessment of enemy launch, Kennedy directed that a World Wide Military Command and Control

System (WWMCCS) be identified and developed to support national strategies. The complexity of the system is staggering, with many computers linked closely together and communicating with far-flung units using radio-frequency bands (14:10).

Complexity has its disadvantages, though. A complex design is more expensive in terms of both dollars and man-hours spent to implement and maintain. It increases the possibility of system "bugs", is more difficult for the average person to understand, and therefore accept, and normally experiences a higher incidence of "software tampering" than does a less complex design (14:78).

WWMCCS witnessed a remarkable improvement in the performance of C3I and a growing dependence on space platforms for communications, intelligence, navigation, and weather. By 1980, over 200 passive military satellites, in various orbital patterns, existed to support the C3I requirements of NATO, the United States, and the Soviet Union (9:9).

The Department of Defense recognizes the importance of command and control in the United States nuclear deterrence policy. In 1983, President Reagan directed an intensive study to define the technologies necessary to defend the U.S. and allies from nuclear ballistic missiles (38:466). The Defensive Technologies Study Team reported their findings in the Strategic Defense Initiative (20).

Strategic Defense Initiative

The Strategic Defense Initiative is a huge, multi-billion dollar research program aimed at exploiting emerging technologies required for intercepting and tracking ballistic missiles. Lt Gen Abrahamson's responsibility is "to design a series of weapons capable of destroying ballistic missiles fired by the Soviet Union--a system of extraordinary complexity, refinement, and strategic significance" (43:5). People tend to relate complexity to poor reliability and, due to the stakes involved in the SDI system, reliability is a non-negotiable requirement.

The immediate goal of the SDI is to research technologies required to intercept ballistic missiles after they have been launched to prevent them from hitting their targets. In the long term, the SDI is looking for ways to defend military targets as well as civilian populations.

Three distinct "echelons" of ballistic missile defense are implied by the SDI mission. They are 1) defense against a counterforce attack (this is probably the most easily accomplished) 2) protection of industrial, transportation, and other types of targets required to sustain warfighting efforts and 3) protection of the civilian population (47:108).

Each of these "echelons" becomes more difficult to defend because of the size involved. In the last instance,

protection of the civilian population, the defense must be essentially leakproof because just a few weapons getting through would cause millions of casualties.

"The purpose of the initial phase of the SDI program is to establish whether--and how soon--these various levels of defensive capabilities can be attained" (47:108).

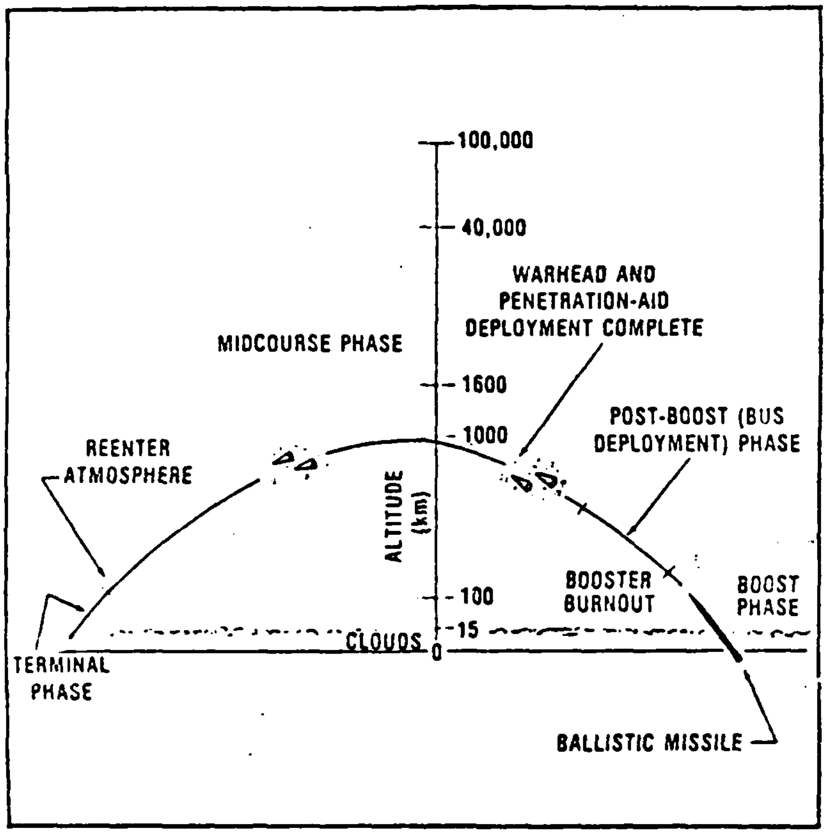
In order to understand the magnitude and complexity of what the SDI hopes to accomplish, brief descriptions and illustrations follow for both a typical ballistic missile trajectory and a conceptual model for the SDI ballistic missile defense.

Ballistic Missile Trajectory

The flight of any ballistic missile can be divided into four generally distinct phases. [See figure 1]

First phase--boost phase. This involves the ascent of the weapon through the atmosphere into space. The rocket engines of the missiles' first and second stages burn brightly at this time and create unambiguous "signatures" that the defender can detect clearly and easily.

Second phase--post-boost phase. In this phase the post boost vehicle (PBV) or "bus" separates from the main engines, maneuvers to achieve various trajectories and then deploys individual reentry vehicles (RVs) on each trajectory (13:52). The RVs consist of a nuclear warhead that can survive reentry and a fusing system to detonate it at the appropriate time. The bus can also be used to deploy decoys or other penetration aids.



Phases of a typical ballistic missile trajectory. During the boost phase, the rocket engines accelerate the missile payload through and out of the atmosphere and provide intense, highly specific observables. A post-boost, or bus deployment, phase occurs next, during which multiple warheads and penetration aids are released from a post-boost vehicle. In the midcourse phase, the warheads and penetration aids travel on trajectories above the atmosphere, and they reenter it in the terminal phase, where they are affected by atmospheric drag.

Figure 1. Phases of a Typical Ballistic Missile Trajectory (20:14).

Third phase--midcourse phase. The multiple warheads and penetration aids travel on ballistic trajectories (free fall) through space, several hundred miles above the earth's surface.

Fourth phase--terminal phase. In this phase the warheads and penetration aids reenter the earth's atmosphere. Reentry typically lasts from 30 to 100 seconds depending on the trajectory and drag characteristics of the RV (3:53). The final event on a missile trajectory is detonation of the nuclear missile's warhead.

From the defender's point of view, the boost phase of ballistic missiles provides the best opportunity for interceptions. Neither the penetration aids nor the individual warheads have been deployed and the defense can thus go after truly worthwhile targets. Also, there is reasonable time available for detecting, tracking, and intercepting the target. "Large Soviet ICBM's and SLBM's burn relatively slowly" (47:108). The boost burn of the SS-18, for instance, lasts about five minutes. "The fastest burning ballistic missile is MX with a burn time of about 150 seconds" (47:108).

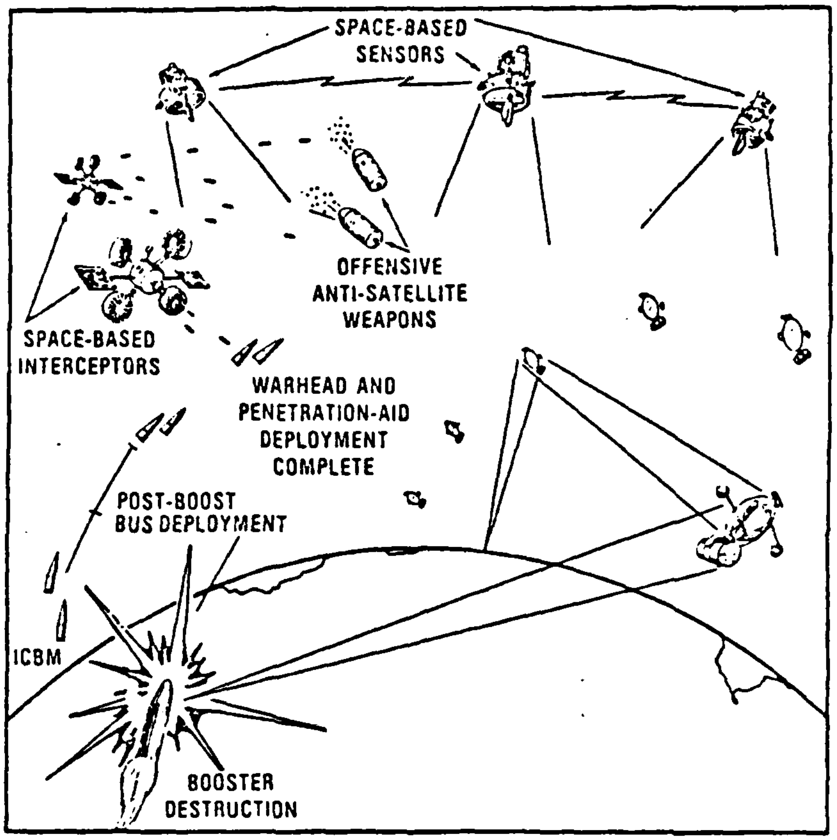
Speed is needed for an effective boost phase interception. SDI, therefore, concentrates on directed-energy (DE) weapons, such as neutral particle beam and high energy laser designs. In the crucial area of acquiring and tracking targets and then pointing DE weapons against them,

the SDI program calls for tests in space of the ability to point with the required degree of accuracy after the targets have been identified and tracked. These demonstrations are essential before moving into SDI's technology validation phase.

During the second and third phases of ballistic missile trajectories, both directed-energy and kinetic energy weapons can theoretically be used against them. Kinetic energy weapons include intercepter missiles and hypervelocity gun systems (47:117).

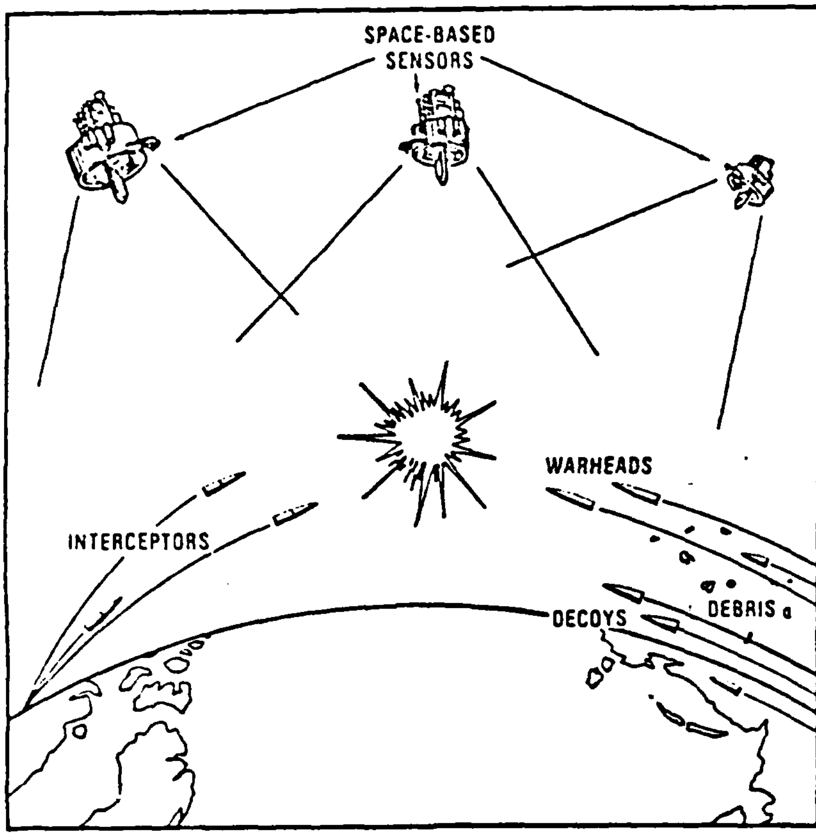
Intercepting warheads in the last phase (the terminal phase) of a missile's trajectory is difficult. The time available is short and differentiating between warheads and decoys poses an "awesome but not impossible task" (47:117). The solution to the differentiation problem may be solved using multi-spectral sensor systems, such as imaging lasers linked with radar and infrared systems (47:117). However, such an approach would create major data transfer and processing tasks for SDI.

Figures 2, 3, and 4 are conceptual illustrations of what the SDI's ballistic missile defense system would be like. In the boost phase [Figure 2] space-based sensors detect the attack. Space-based interceptors protect the sensors from offensive anti-satellite weapons and also attack the oncoming missiles. During the midcourse phase [Figure 3] the space-based sensors must continually



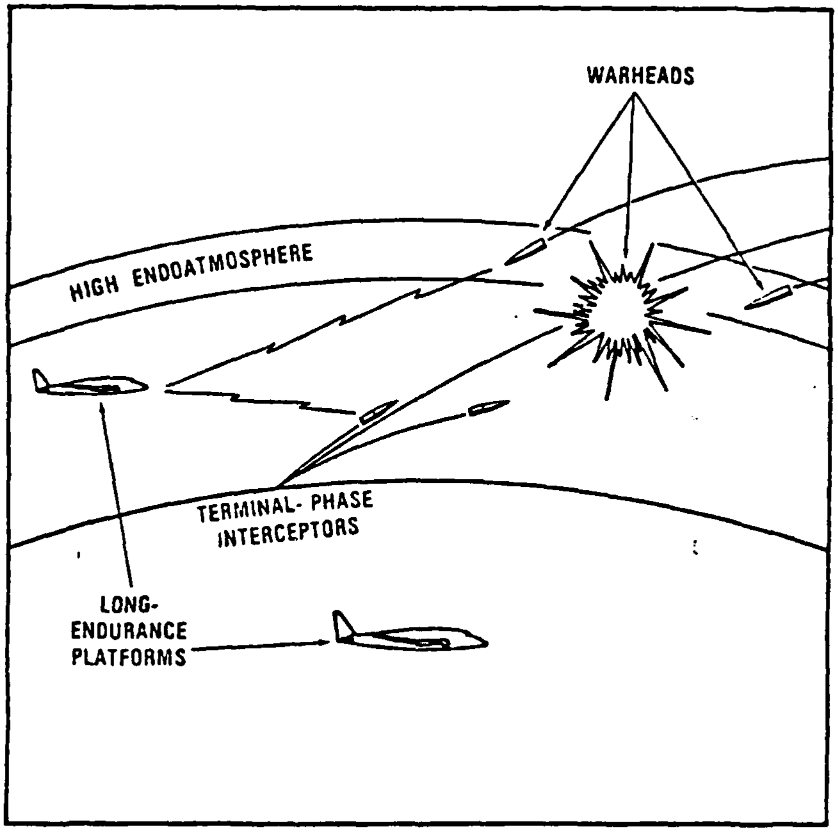
Strawman concept for ballistic missile defense during the boost phase. An essential requirement is a global, full-time surveillance capability to detect an attack and define its destination and intensity, determine targeted areas, and provide data to guide boost-phase intercept and post-boost vehicle tracking systems. Attacks may range from a few missiles to a massive, simultaneous launch. For every booster destroyed, the number of objects to be identified and sorted out by the remaining elements of a multitiered defense system will be reduced significantly. An early defensive response will minimize the numbers of deployed penetration aids. The transition (post-boost phase) from boost phase to midcourse allows additional time for intercept by boost-phase weapons and for discrimination between warheads and deception objects. Space-based sensors detect and define the attack. Space-based interceptors protect the sensors from offensive anti-satellite weapons and, as a secondary mission, attack the missiles. In this depiction nonnuclear, direct-impact projectiles are used against the offensive weapons.

Figure 2. SDI Ballistic Missile Defense--Boost Phase (20:15)



Strawman concept for ballistic missile defense during the midcourse phase. Intercept outside the atmosphere during the midcourse phase requires the defense to cope with decoys designed to attract interceptors and exhaust the defending force. Continuing discrimination of nonthreatening objects and continuing attrition of reentry vehicles will reduce the pressure on the terminal-phase system. Engagement times are longer here than in other phases. The figure shows space-based sensors that discriminate among the warheads, decoys, and debris and the interceptors that the defense has committed. The nonnuclear, direct-impact projectiles speed toward warheads that the sensors have identified.

Figure 3. SDI Ballistic Missile Defense--Midcourse Phase (20:16).



Strawman concept for ballistic missile defense during the terminal phase. This phase is the final line of defense. Threatening objects include warheads shot at but not destroyed, objects never detected, and decoys neither discriminated nor destroyed. These objects must be dealt with by terminal-phase interceptors. An airborne optical adjunct is shown here. Reentry vehicles are detected in late exoatmospheric flight with sensors on these long-endurance platforms. The interceptors—nonnuclear, direct-impact projectiles—are guided to the warheads that survived the engagements in previous phases.

Figure 4. SDI Ballistic Missile Defense--Terminal Phase (20:17).

discriminate among decoys, debris, warheads and the interceptors that the defense has already committed. The terminal phase [Figure 4] is the final line of defense. Reentry vehicles are detected with sensors on long-endurance platforms. Interceptors are guided toward warheads that survived the previous phases.

Command and control for ballistic missile defense raises two issues to which technology cannot provide an answer. The first is the impossibility of testing the whole defense system in a realistic wartime setting. The second issue is the likely need for the system to be autonomous, since there would be very little time for human decision (12:41).

Battle Management

As mentioned previously, in the years ahead more than 50% of all SDI funding will be directed at battle management. While there is least theoretical evidence that reasonably effective kill mechanisms for the various layers of a ballistic missile defense system can be developed over time, serious questions remain about SDI's battle management. Included in this battle management program are command, control, communications, and intelligence (C3I) and surveillance, acquisition, tracking, and kill assessment (SATKA). Specifically, concerns are in the areas of system architecture, software structure, and data processing (46:53).

A major challenge is to ensure that the Battle Management/Command and control system can function in an intense nuclear environment. In addition, SDI's BM/C3 component system must also be able to work under direct attack of electronic and other countermeasures. The final goal is to develop a highly reliable, responsive, survivable, endurable, and cost effective BM/C3 system (47:118).

In the SDI, BM/C3 systems are tied to surveillance, acquisition, tracking, and kill assessment (SATKA). These systems range from sensing of information that triggers defense engagement to battle management and assessment of the status of forces before and during the engagement.

"The correlation and fusion of information from sensor systems is becoming increasingly important for military command and control and for technical intelligence analysis" (37:55). High data rates from increasingly sophisticated sensors are overwhelming the existing methods of processing this data. The high volume of data makes timely interpretation difficult and very demanding of human resources. It would be very beneficial to have a system that processes routine information automatically thereby freeing the human analyst to concentrate on more non-routine tasks.

Just as in a human decision-making process, the effectiveness of a computerized battle management system is

directly related to the quality of the information used to make a particular decision. Therefore, some method of system control must be enforced to ensure that only authorized rule changes are input, only reliable data updates are made, and all unauthorized access attempts are denied and reported. Such security and protection measures are not easily accomplished.

However, the result of making an error in the SDI environment could be fatal and have disastrous effects on the country. Some form of over-ride (or "fail-safe") mechanism must be incorporated to prevent a potential catastrophe from occurring (14:79).

A White House Panel known as the (Dr. James) Fletcher Defensive Technologies Study Group has pointed out that, in the past,

> technology in computer hardware and software and signal processing was incapable of supporting battle management for a multi-layered defense. Today, the rapid advancement of technologies is believed to permit realization of the complex command and control systems needed. (47:118)

The SDI organization is using an "accelerated procurement concept" involving many parallel studies done by different segments of industry. The individual studies will be based on simplified requests for proposals that will give industry more freedom in isolating key tradeoffs, establishing alternative architectural concepts and being more creative.

Much is expected from SDI's BM/C3 component. If a multi-tiered defense were deployed, it would require positive control of its operations. It would have to be reliable enough to turn on when needed and still be safe when it is not needed. However, it must still be a credible threat to the Soviets.

The credibility of the system must be based on a demonstrated capability to manage surveillance, tracking, and intercept actions in a complex defense system. This is going to be a difficult order to fill. The information processing task associated with gathering and combining huge amounts of data from large numbers of sensors places unprecedented demands on software development. Because evaluation and demonstration of SDI's BM/C3 component will largely depend on simulation, development of realistic modeling and simulation techniques is urgent and crucial (47:118).

Artificial Intelligence

The goals of the field of Artificial Intelligence can be defined as (1) to make computers more useful and (2) to understand the principles that make intelligence possible (50:1). Computers need to be made more useful because, as the world grows more complex, computers will be needed to perform tasks that are very time-consuming and difficult for humans. One difficulty is that solving certain problems can result in a combinatorial explosion of possibilities that

exhaust memory capabilities of even large computers. More precisely, traditional algorithmic approaches aimed at solving these problems never reach a solution. AI efforts have been directed at making the time versus problem size curve grow as slowly as possible even when it must grow exponentially.

It is very difficult to define artificial intelligence in precise terms. Many authors have tried but no universally acceptable definition exists. Elaine Rich, in her book on AI, defines artificial intelligence as the study of how to make computers do things which, at the moment, people do better (39:1). Patrick Henry Winston defines AI as the study of ideas that enable computers to be intelligent (50:1). Barr and Feigenbaum, in their _Handbook of Artificial Intelligence_, define AI as the part of computer science concerned with designing intelligent computer systems that can exhibit the characteristics we associate with intelligence in human behavior (i.e understanding language, learning, reasoning, and problem solving) (4:3).

What the authors do agree on is that many problems fall within the scope of artificial intelligence and many applications of AI do exist. Areas of study include natural language processing, intelligent retrieval from data bases, expert consulting systems, theorem proving, robotics, automatic programming, and perception problems. The

following discussion explains each area of study in more detail (35:2-7).

Natural language processing. It is a very difficult task to develop computer systems that can understand natural language. The computer system must have both contextual knowledge and the processes for making inferences assumed by the sender of the message. Some progress has been made in developing computer systems that understand both written and spoken language.

Intelligent retrieval from databases. Databases store large amounts of data on specific subjects. A computer system that can understand a query, search for the appropriate data, and then deduce the answer from the stored facts would be very useful.

Expert consulting systems. AI has been used in consulting systems that provide users with expert conclusions about specialized subject areas. Systems have been built that diagnose diseases, diagnose satellite malfunctions, determine shuttle manifesting (what missions, what payloads, and when), and evaluate potential ore deposits. A major problem in developing expert systems is how to represent the knowledge that human experts possess.

Theorem proving. The study of theorem proving has helped in the development of AI methods. The formalization of the required deductive processes helps in understanding more clearly some of the components of reasoning.

Robotics. Research on robotics has been a help in the development of many AI ideas. It has helped in understanding how to generate plans for action sequences and how to monitor the execution of these plans.

Automatic programming. It can be said that compilers already do "automatic programming." They take in a complete source code specification and write an object code program. Automatic programming in the AI sense refers to a program that takes in a high-level description of what the program is to accomplish and produces a program. Some automatic programming systems also provide program verification which is very useful.

Perception problems. The study of AI in perception involves many steps. First a visual scene is encoded by sensors. The data is processed by detectors that search for simple picture components (i.e. line, curve, corner). These are processed to infer information about 3-D objects. The ultimate goal is to represent the scene by an appropriate model. The final representation can contain colors, spatial relationships and measurements.

An AI technique is a method that exploits knowledge that should be represented in such a way that all of the following are true (39:5-6). It captures generalizations. It is therefore not necessary to represent separately each individual situation. It must be able to be easily modified to correct errors and to reflect changes in the world and in

our world view. It can be used in a great many situations even if it is not totally accurate or complete. It can reduce the range of possibilities that must usually be considered. Although AI techniques must be designed in keeping with these constraints, there is some degree of independence between problems and problem solving techniques. It is possible to solve AI problems without using AI techniques (but the solutions may not be very good). And it is possible to apply AI techniques to the solution of non-AI problems. The following two sections are descriptions of the more commonly used AI techniques.

Expert Systems Technology

"Expert systems are a class of computer programs that can advise, analyze, categorize, communicate, consult, design, diagnose, explain, explore, forecast, form concepts, identify, interpret, justify, learn, manage, monitor, plan, present, retrieve, schedule, test, and tutor" (34:303).

Expert systems are usually developed with the help of human experts and attempt to represent the expert's knowledge. Experts tend to solve problems that are unstructured and ill-defined, usually in a setting that involves diagnosis or planning. They cope with the lack of structure by applying heuristics or rules-of-thumb to solve problems when lack of time or understanding prevents full analysis.

The nature of expertise encompasses a whole range of behaviors including:

1. solve the problem
2. explain the result
3. learn
4. reconstruct knowledge
5. break rules
6. determine relevance
7. degrade gracefully (18:4).

Solving the problem is the most obvious and necessary but alone is insufficient.

Expert systems have been designed and developed during the last two decades for many different applications. They have been found especially useful in areas requiring flexibility, human-like processing and ease of expression. They are useful in areas of high uncertainty and have already been used as consultants. Each of these areas is discussed in more detail below.

Flexibility of expression. Expert systems are able to use the rules-of-thumb that practitioners tend to carry around in their heads but never write down. Expert systems present a possible alternative to conventional computer models, especially where the relations are known but difficult to reduce to equations or where they are too complex for the purpose of the system (5:463).

Human-like processing. Compared to conventional computer programs, expert systems operate at a level and in terms and concepts with which the user can feel an affinity. They perform at a level of rules and facts and the

relationships between them rather than at a level of program steps (5:464).

Ease of expression. Languages in which the knowledge-base is expressed can be closer to the sort of language used by specialists than "conventional" programming languages (5:464).

Uncertainty. Expert systems can be used in areas of incomplete knowledge and where judgement is needed. This is because they usually contain plausible-inference systems (5:465).

Consultancy. Expert systems have already been used as consultants. Expert systems tend to be more reliable, be more consistent, have increased accessibility, have the ability to try a greater number of alternatives in the time available, arrive at a solution faster, and allow for easier duplication of expertise (i.e. copy a disc file versus retrain) (5:466).

Among the successful rule-based expert systems that have been developed are:

1. MYCIN--diagnoses infections
2. HEURISTIC DENDRAL--identifies organic compounds
3. PROSPECTOR--aids geologists in evaluating mineral sites
4. PUFF--analyzes pulmonary function tests
5. INTERNIST--performs diagnosis in internal medicine
6. XCON (formerly R1)--configures the VAX-11/780 computer system
7. SACON--provides engineers with advice on structural analysis (34:306).

The field of expert systems is expected to develop rapidly in areas of great commercial interest, such as energy and minerals, home entertainment, office automation, and military systems (28:28).

To further illustrate the applications of expert systems consider the following systems that have already been built for space application. The Johnson Space Center has developed a Resource Planning and Management System (RPMS). The RPMS is an "architectural design for expert systems to handle scheduling problems" (8). The videocassette presented a demonstration on shuttle manifesting--what missions, what payloads, and when. The three main advantages for this system are 1) a user friendly interactive scheme, 2) an easily accessible and intelligent database, and 3) the ability to bring expert knowledge to bear in a scheduling problem.

A recent masters thesis addressed the issue of "Artificial Intelligence in Space Platforms" (51). It concluded that, "The development of expert systems is ripe for spacecraft exploitation" (51:100). The cost of development and testing of an expert system on the Defense Satellite Communication System (DCCS), a typical space platform, is approximately $2.1M (51). Another $14.2M would be required for the hardware to outfit the DCCS. Expert systems technology can be very useful but also very expensive.

IntelliCorp has developed KEE--a Knowledge Engineering Environment. It is a set of softwares tools designed to assist system developers in building their own knowledge-based systems. (Similar products are ART-Automated Reasoning Tool by Inference Corp in Los Angeles CA and S1 by Teknowledge in Menlo Park CA.) KEE is a hybrid system, in that it incorporates several well-proven AI methodologies including object-oriented programming, frame-based knowledge representation, rule-based reasoning, data-driven reasoning, and LISP functional programming (33:1). These methodologies are accessible to the user via a graphical interface.

An interesting example of the KEE system's usefulness is an application under development at Ford Aerospace & Communication Corporation. This system will help satellite operators diagnose and correct spacecraft malfunctions.

A system under development at MITRE labs will monitor oxygen levels for the space shuttle. It is called LES for LOX (Liquid oxygen) Expert System (42). A highly automated, computerized system already exists on the shuttle and the LES system is expected to improve the old one.

Despite their successes, current expert systems suffer from a variety of limitations. Among these shortcomings are: overly narrow domains of expertise, inadequate communication channels with the user (i.e. the need for better natural language), inability to represent certain kinds of knowledge easily (i.e. knowledge about processes,

time, and three-dimensional space), and the great difficulty of building and modifying the expert knowledge bases on which these systems are based (48:60).

One of the most difficult tasks in building expert systems is in exacting and applying the cognitive process (35:58). It is extremely difficult and time consuming to duplicate all the knowledge and thought processes of a human expert who has been acquiring them all through life. For instance, even the simplest daily routines that are carried out reflect decisions based on years of reinforced experiences and intuition. The dynamic, high-stress environment of combat will certainly require much greater preparation. This helps illustrate the complex nature of applying AI to command and control.

Still other areas that are limiting the use of expert systems and could use more research are system development and competence (48:61). It currently takes several man-years to develop an expert system using a programmer with an AI background. And the expert systems that have been developed thus far are for a "single customer"---too specialized. The competence of these systems is lacking in that they do not have the capability to check their conclusions for plausibility. Also, since knowledge tends to be at a "surface" level, systems are unable to infer missing knowledge from general principles.

Frederick Hayes-Roth, an expert in the AI field, stated in a recent paper that development in expert systems technology should follow a somewhat predictable course (27:265). In the near future emphasis is anticipated on 1) intelligent instruments that couple data collection with expert data interpretation and 2) numerous high-value, specialized systems. "Developments in expert-system technology are expected to lead over time to the construction of high-value knowledge bases" (27:265). Steady improvements in these directions should reduce costs, expand capability, and increase reliability, making an already practical knowledge systems technology much more so.

Knowledge-based Systems

Knowledge-based, expert systems (KBS) or "knowledge systems" have evolved over a 15 year period from laboratory curiosities of applied artificial intelligence into targets of significant technological and commercial developments efforts (27:263).

An expert or knowledge-based system is composed of three major components: a situation database, a knowledge database, and a control system (24:19). The situation database contains a representation of the current situation including all relevant background information. The knowledge database contains all the expertise. The control system decides how best to apply the knowledge base to the situation database. In essence, the control system is the

applications software that must be written and tailored to solve the designated problem.

"Knowledge systems convert the inactive knowledge in books and manuals and the private know-how of experts into inspectable, electronic, active forms" (27:269). Knowledge systems address problems that arise from difficulties in retaining, transmitting, and applying know-how. They provide a means to employ know-how where it is needed, when it is needed, and at great speed. "These are the qualities that attract those in factory automation, process control, safety systems, military intelligence, and weapon systems" (27:268).

Lt Gen Lincoln D. Faurer, Director of the National Security Agency, speaking at an Air Force Association Symposium, singled out knowledge-based systems as appearing to offer the capability to provide a uniform base of experience and background information to use in rapidly interpreting and managing huge quantities of data (45:98). He suggested KBS could "asimilate larger and larger volumes of raw, uncorrelated data to enable timely detection and reporting of key events and indicators" (45:98). He pointed out that recent work in the AI community can be brought to bear on the problem of processing, analyzing, and interpreting vast amounts of data in near real-time. "Attaining such capabilities is crucial," he stressed because, "the decision windows in today's world can be

measured in minutes and seconds, and we clearly must use all available technology to keep the windows as wide as possible" (45:98).

While many applications in knowledge based systems technology seem fairly straightforward, others present challenges that go beyond our current technology and capabilities. The barriers most frequently encountered include:

1. a need for flexible and general natural language understanding (This may arise when users need to exercise initiative in directing the activities of a knowledge system.),

2. a need to incorporate knowledge that is hard to represent (situations requiring spatial or temporal reasoning),

3. a need to combine and unify the knowledge of multiple experts without benefit of established standards, and

4. a need to apply broad bodies of knowledge quickly (A need that may arise in solving command and control problems.) (27:269).

Architectural Principles

"The 1980's will continue to see distributed architectures made up of personal computers, each with the capabilities and speed of mainframes popular a decade earlier" (11:259). Personal computers share tasks and results and communicate with central processing facilities. The central processing facilities maintain and support the common databases and perform massive number-crunching tasks for network support.

This architectural concept has been adopted in military command and control, among many other applications. Such architectures conserve resources, enhance survivability, provide flexibility and adaptability, and minimize reliance on communications (5:259). However, the price for these advantages is our increased dependence on communication security in a military environment and the increased need to achieve overall system survivability and reliability.

Looking at the software aspect of expert systems a different set of architectural principles evolve. These involve the design of the expert system itself. An article by Randall Davis of the MIT AI Laboratory listed the following principles as applying to knowledge based expert systems:

> 1. Separate the inference engine and the knowledge base. By doing so the knowledge in the knowledge base is more easily identified, more explicit, and more accessible. If the two are inter-mixed, domain knowledge becomes spread out through the inference engine, it becomes less clear what we ought to change to improve the system, amd flexibility suffers.
>
> 2. Uniformity of representation. This cuts down on the number of mechanisms required, keeping system design simpler and more transparent.
>
> 3. Keep the inference engine simple. When the inference engine is less complicated, less work is needed to determine exactly what knowledge is needed to add to improve the system performance. Knowledge acquisition becomes easier.
>
> 4. Exploit redundancy. Find multiple overlapping sources of knowledge with different areas of knowledge with different areas of strengths and different shortcomings. Properly used, the entire collection of knowledge sources can be better than any of them taken alone. Redundancy can be a remedy for incomplete and inexact knowledge. (18:6)

Following the above architectural principles will serve to mold the three basic components (the knowledge base, the inference engine, and the data base) into a cohesive unit.

Commercialization of Knowledge System Technology

Knowledge systems and tools for creating them have already entered the commercial world. The first systems grew out of long-term academic research. Recently, three types of commercial applications have emerged:

> 1. tools for the construction of knowledge systems,
> 2. specialized hardware and systems software for general AI programming, and
> 3. the commercial expert system, a problem specific artificial advisor (27:270)

Figure 5 illustrates the current and future state of commercialization of knowledge systems technology. The innermost hexagon represents the major ingredients of knowledge system technology, and the three outer rings represent increasing technology commercialization. The first ring represents the types of commercial products now available. The second ring portrays primary areas of new product focus anticipated in the next three years. And the outermost ring contains the key midterm commercial targets the author (Hayes-Roth) expects companies to hit by 1990. Of relevance to command and control are military strategic applications, planning and control, specialized inference machines and multiprocessor architectures.

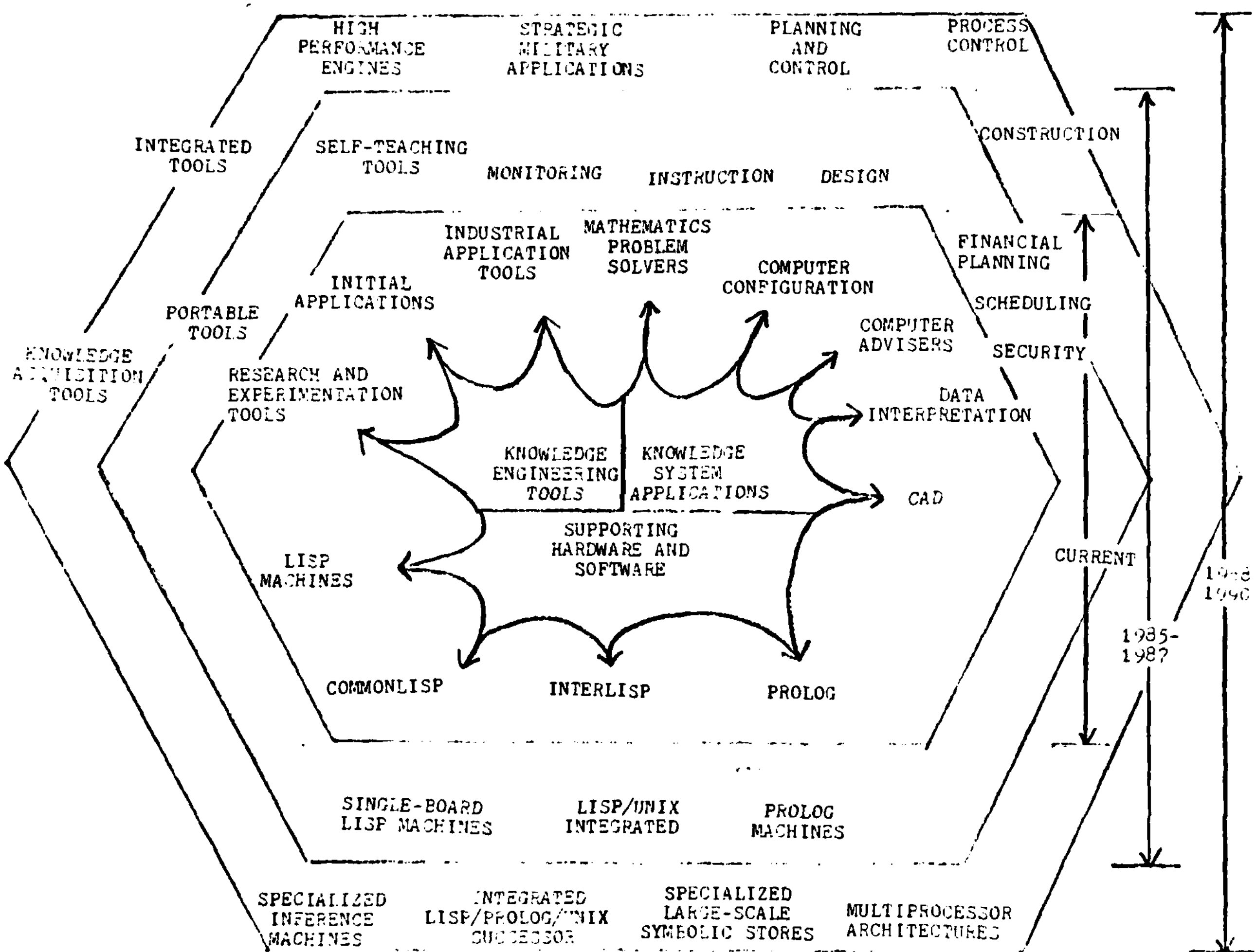


Figure 5. The Commercialization of Knowledge System Technology (27:270).

C2 Relevance to AI

A study performed by the Naval Ocean Systems Center in San Diego, CA for the Naval Electronic Systems Command addressed the area of C2 Relevance to Artificial Intelligence (7). The report consisted of a survey and evaluation of artificial intelligence systems for applicability to command and control. The evaluation criteria was based on availability, applicability and maturity. Areas that seemed most appropriate for this study included KNOBS, inference systems, natural language processing, and planning and problem solving.

KNOBS. KNOBS (from knowledge based systems) is an integrated collection of AI programs directed toward the development of experimental tactical mission planning (23). It is classified as a knowledge representation system and exists in INTERLISP.

KNOBS is clearly oriented toward military applications and as such is applicable to command and control. It is an integrated system, combining knowledge representation with a natural language interface and some inferential capability.

Inference Systems. "Inference is the process of drawing conclusions, of adding information to a knowledge (data) base on the basis of information that is already there" (7:8). Inference can be inductive or deductive. A useful inference system is rule-based. Knowledge is structured in rules that are applied to the facts to reach conclusions.

Most of the tasks in the command and control domain require some form of inference, of drawing conclusions from known facts. An inference system for command and control tasks must be capable of dealing with information common to the command and control domain. This means the inference system must be adaptable enough to work in or with the knowledge representation framework chosen for a task. "Flexibility with respect to knowledge representation therefore becomes a major criteria in evaluating systems" (27:8).

Natural Language Processing (NLP). The ability to use a natural language such as English to communicate with a computer has long been a goal of artificial intelligence researchers. A language understanding and generating capability could conceivably remove many obstacles that presently obstruct the human-machine interface. Additionally, this may make the SDI more feasible because humans can monitor and communicate with the system. Thus, the system need not be completely autonomous.

Natural language programming is relevant to command and control in at least two ways.

1. Much of the present data that needs to be used by an automated command and control system is already in natural language form. NLP can assist in obtaining this information.

2. NLP could be used to improve the interface between the automated system and its users, making the interface friendlier and more responsive. (i.e. AI makes it easier for the "Man in the Loop" to be used effectively.)

Planning and Problem Solving. Planning and problem solving is at the heart of the command and control domain. It is the process of determining, examining, and deciding among alternatives. Knowledge representation, natural language interfaces, and inference systems can all support the assessment and decision processes.

Command and control planning systems could be used to support decision-making by providing an independent source of possible courses of action, accompanying justifications, and assistance in monitoring the execution of selected courses of action. Where possible a command and control planning system should be able to "learn" common sequences of actions so that costly replanning for common occurrences does not happen.

Simulation

Some work has been done in applying AI to the military command and control environment. A simulator has been developed as the first step toward actually monitoring an air battle. Applying concepts in computer science, artificial intelligence, and expert systems, the RAND corporation has developed a prototype air battle simulator

called SWIRL to demonstrate the payoff of the new technology to military simulations (32:v). SWIRL is designed to simulate military air battles between offensive and defensive forces (31:331-4).

SWIRL is a design tool for military strategists in the domain of air battles. It contains knowledge about offensive and defensive battle strategies and tactics. SWIRL accepts environmental specifications representing offensive and defensive forces from the user and then uses its knowledge base to produce a simulation of the air battle.

In SWIRL's air battle domain, penetrators enter an airspace with a pre-planned route and bombing mission. The defensive forces try to eliminate these penetrators. Many factors are considered during the simulation. The following list comprises elements of the air battle domain (31:331-2):

1. Penetrators--primary offensive objects
2. Ground control intercept radar
3. AWACS--airborne radar
4. Surface-to-air missile installations
5. Missiles
6. Filter centers--integrate and interpret radar reports
7. Fighter bases
8. Fighters
9. Command centers
10. Targets

The flow of command and control through these objects is modeled in ROSS (an object-oriented programming language) for the SWIRL simulation.

A report on Automated War Gaming contained some useful insights on architectures and design requirements to consider when exploring strategic command and control issues (17). It stated that a "conceptual architecture" is needed for an approach to include C3I rather than a "grab bag of physical models and AI techniques" (17:12). In addition, several design requirements were noted. These include:

1. The approach should be top-down rather than bottom-up. This implies we should focus on C3I functions rather than individual systems.

2. The character of the system must account for the existence of multiple levels and locations within levels of command and control authority. It should reflect a hierarchical phenomena.

3. Even the early efforts to reflect C2 should be useful and realistic. It is better to reflect some of the real command and control issues early than to treat C2 comprehensively for a "toy problem" of no direct value.

4. The approach should be evolutionary and should allow linkup to some of the work being conducted within the defense community.

ADA

Although not currently an artificial intelligence programming language, ADA will be briefly addressed since it will assume a vital role as automated military computer systems are fielded in the 1990's. ADA is the Department of Defense's solution to reduce cost and increase the quality of military applications software. The intention is that all new software be written in ADA as early as 1990, with a phase-in period through the late 1980's (24:33).

ADA contains many features found in other computer languages and its structure is expected to simplify software maintenance. It has English-like syntax allowing for increased readability. Since ADA will be the standard, the need to train programmers in application-specific languages will be reduced. ADA's appropriateness to military applications, along with expected widespread availability of reusable components, are providing a great incentive for Department of Defense applications.

Unfortunately, the development of expert systems in a standard programming language is very difficult. Many AI programming languages, such as INTERLISP and PROLOG, are specifically designed for AI. Reimplementing an existing expert system in ADA is possible, but it would be expensive and tedious.

One potential conflict arises in the type of processing of computers for AI use. Expert systems require cyclical or continuous processing for best efficiency, whereas conventional computers use sequential processing (BB:34). To resolve this conflict, ADA will be enhanced to be able to perform in AI systems.

Future Trends in AI

Hayes-Roth concluded his article with three basic trends that AI is heading toward in the future.

> 1. This technology [knowledge systems] will spawn many new and speculative products.
> 2. The broad penetration of knowledge into industrial and commercial organizations.
> 3. A trend toward closer integration of knowledge systems and data processing (27:272).

It is the last trend listed that looks the most promising for applications toward command and control.

Knowledge systems technology currently underway emphasizes several industrial and commercial applications. These include expert systems for equipment repair, heuristic control systems for military functions and industrial automation, knowledge-aided design systems, knowledge-based planning aids, and automated interpretation systems for sensors and instruments (27:273). Command and control systems could benefit through the use of these applications.

Initiatives in artificial intelligence by the Department of Defense, and spearheaded by DARPA and NASA, put immediate emphasis on designing expert systems to assist the decision-maker with C3 mission planning, scheduling, targeting, decision-making, intelligence analysis, and other C3 functions (11:258).

Command and control centers will need to remain current of the advances in AI. Periodic briefings and visits to

universities and research and development companies would help to ensure that systems acquired for near and intermediate terms will be compatible with the transition to AI systems (24:63, 48:66).

In the near term, development of practical AI capabilities for C3I functions will probably be limited to the expert type systems capabilities used by the computer industry (44:75). More dramatic AI breakthroughs where complex human thinking processes can be duplicated are areas for further research and development (44:75).

Data from existing efforts (in expert systems) seems to suggest that even in the best of cases, at least five man-years worth of effort is necessary before the system even begins to perform reliably (18:22). So, we are looking many years in the future before a system will be operational.

However, there appears to be a trend toward shorter development times for expert systems. Randall Davis, of the MIT AI Lab performed an informal survey to determine expert system development times. Figure 6 is a graph of his results. His graph shows a decrease in development times as AI technology has matured. It is logical to expect that development times will continue to decrease as AI tools become even better.

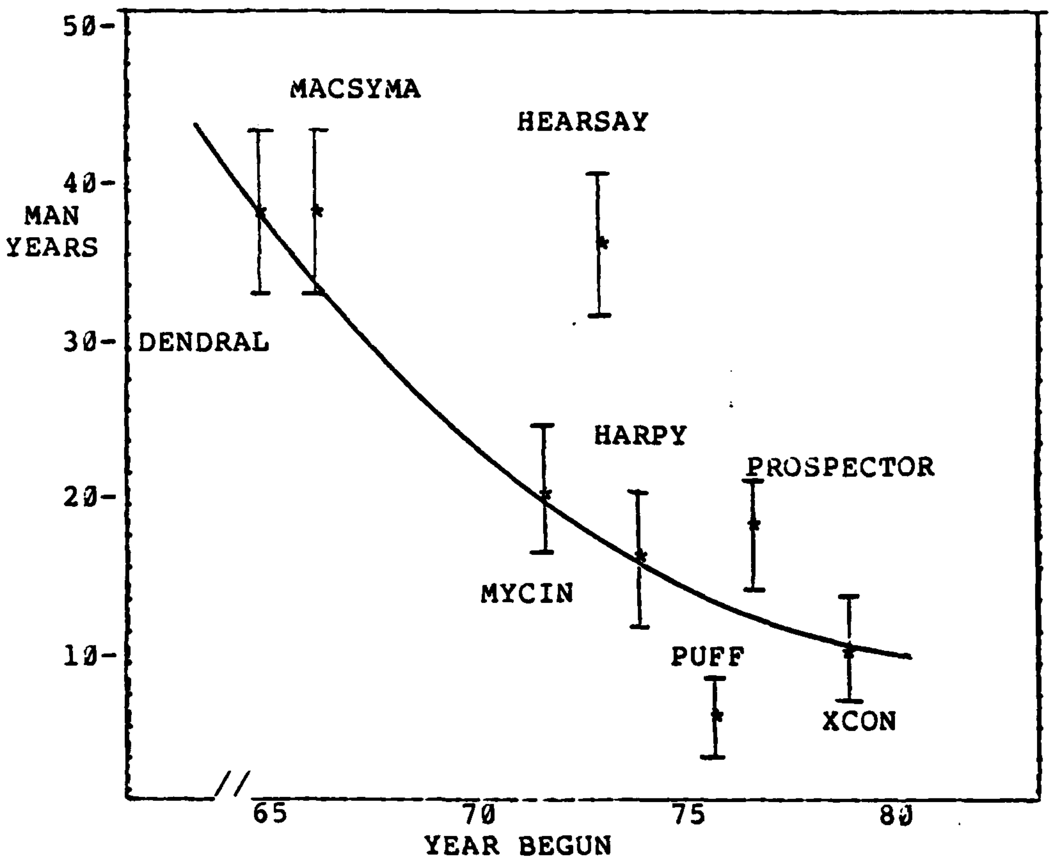


Figure 6. Expert System Development Time (18:10)

Chapter Summary

This chapter has described the evolution of the U.S. command and control structure from the start of the nuclear age to the present. Command and control systems of the future are heading towards space defense. The Strategic Defense Initiative hopes to accomplish, as one of its objectives, a space-based battle management/command and control system. The purpose of battle management is to make the best use of defense resources. It is a data processing and communication system whose tasks include situation monitoring, resource accounting, resource allocating, and reporting.

The Strategic Defense Initiative is still in the research and development stage and funds in the billions of dollars are earmarked for the SDI. It is hoped that before the next century a space-based defense system will be operational.

However, the technologies needed to develop the system are not available today. A tremendous amount of research and development is required to use emerging technologies in the best interests of the SDI.

One area that promises to be very useful is artificial intelligence. A fairly new discipline, AI is rapidly expanding and evolving. Many applications of AI can help the SDI realize its goals of a battle management/command and control system.

This chapter has provided the foundation for further research and discussion. Based on this extensive literature review, evaluation criteria will be developed and used to analyze responses received during personal and telephone interviews. Chapter III, Research Methodology, goes into more detail in these areas.

III. Research Methodology

This chapter discusses the procedures used to collect and analyze available information in order to satisfy the research objectives proposed in Chapter I. Specifically, it focuses on data collection by means of a literature review, personal interviews and telephone interviews.

Data Collection

The first research objective deals with identifying command and control technology that could benefit from the use of AI. The second research objective deals with identifying various artificial intelligence techniques applicable to Battle Management/Command, Control, and Communications. In order to satisfy these objectives, an extensive literature review, telephone interviews and personal interviews were performed.

Literature Review. The literature review provided an information baseline for further research endeavors and consisted of the following sources:

1. Air Force Institute of Technology (AFIT) Libraries. Many computer and engineering journals and magazines are located in these libraries. Useful ones included the *Proceedings of the International Joint Conference of Artificial Intelligence* (IJCAI), *Signal* Magazine and *AI Magazine*.

2. Defense Technical Information Center (DTIC). Extensive use was made of DTIC to gather information from all areas of the Department of Defense relating to Artificial Intelligence and Command and Control.

3. Air Force Publication Library. The Wright-Patterson Air Force Base, Aeronautical Systems Division (ASD) publications library provided information from Air Force Regulations.

4. Air Force Wright Aeronautical Laboratory (AFWAL) technical library. The Wright-Patterson Air Force Base AFWAL library was a source of additional journals used in this research effort.

5. Wright State Library. Many recent textbooks on Artificial Intelligence and on Command and Control were located here.

Interviews. After considering the intent of the research effort, the level and nature of the data needed, and the availability of adequate respondents, a "personal interview" approach was chosen to complete the data collection. Usually the interview approach is the only practical way to gather opinions, intentions, or knowledge (22:213). Once the approach was selected, the communication mode was developed.

The communication mode involved a series of questions used as an interview guide. These questions were developed with the awareness that sequencing, wording, respondent

sensitivity, and content influence the instrument development process (22:Chapter 8). In particular, question content had the greatest impact on the process. To overcome this problem, the following questions were considered:

1. Should the question be asked?
2. Is the question of proper scope?
3. Can the respondent answer adequately?
4. Will the respondent answer adequately?

The interview questions were designed around the literature review from the previous chapter. The section on AI techniques and applications made up the basic framework for the interview questions. Routine questions such as name, rank, position, and experience were then added.

Before any interviews can take place, the organizations involved with the interview process must be chosen. The criteria for selection included the following:

1. The organization must be actively doing research in Artificial Intelligence.
2. The organization must be familiar with Command and Control technology.
3. The organization should be currently participating in research for the Strategic Defense Initiative.
4. The organization must be accessible to the researcher.
5. The organization must be willing to provide information.

Using the above criteria the following organizations were chosen:

1. Rome Air Development Center, Griffiss AFB NY
2. Aeronautical Systems Division, Wright-Patterson AFB OH
3. Space Division, Los Angeles CA
4. Space Technology Center, Kirtland AFB NM
5. Space Command HQ, Peterson AFB CO
6. SDI Office, office of Sec of Def, Washington DC

Data Analysis

Since the research objectives in Chapter I are subjective in nature, it follows that the research analysis will also be subjective. In addition, since the research covers a large variety of techniques/applications and concepts, each with its own uniqueness, the information does not lend itself to statistical analysis.

Criteria. Before any analysis can start, criteria must be established on which judgement may be based. After reviewing the literature, it was decided that the use of the opinions represented in the literature was the most effective method of identifying the criteria needed for analysis. Those topics that recur most often in the literature were selected as the criteria needed for comparing and critiquing. To be more specific, the following criteria were chosen:

1. Risk

2. Generic Architecture
3. Survivability
4. Reliability
5. Data Processing
6. Flexibility
7. Adaptability
8. Real-Time response capability
9. Complexity
10. Implementation Language

Each of these criteria are addressed in the interview guide.

Interview Guide

An abbreviated version of the interview guide that was used during interviews is included in Appendix A. What follows is a detailed interview guide that includes the reasoning and justification behind the questions asked.

Background. To determine if the interviewee is familiar enough with Artificial Intelligence or Command and Control to adequately answer questions.

What is your name? Organization?

What is your position/job title?

What is your education level? (M.S., B.S.)

What is your area of expertise?

Artificial Intelligence. The science of trying to get machines to think, reason and infer as humans do. An emerging technology with potential to be a powerful tool.

Are you familiar with AI?

Have you worked in the AI area?

What areas of AI do you feel hold the most promise for the future?

-natural language processing

-intelligent retrieval from data bases

-expert consulting systems

-theorem proving

-robotics

-automatic programming

-perception

-expert systems

-knowledge-based systems

Is there enough user acceptance of AI?

Battle Management/Command, Control and Communications. BM/C3 is a complex of equipment, people and algorithms that operate command facilities, communications systems, support systems, data processing systems, and collectors and sensors.

Battle Management involves making the best use of defense resources. (includes situation monitoring, resource accounting, resource allocation, and reporting)

Command and Control is the exercise of authority and direction over assigned forces. (including force and air battle management, air surveillance, aircraft I.D., strike control, electronic warfare, communications, information and intelligence collection, sensor management, data processing, and logistics support)

Are you familiar with command and control?

Have you worked in this area?

What areas of command and control are getting the most attention today? (only unclassified topics)

Do you think AI could benefit command and control? How?

Areas of concern in BM/C3:

-system architecture

-software structure

-data processing

Could AI help in these areas? Explain?

Strategic Defense Initiative. A huge multi-billion dollar research and development effort aimed at developing technologies that can provide an effective defense against ballistic missiles. This thesis is concerned with how AI could be applied to the BM/C3 objective of the Strategic Defense Initiative.

Is your organization doing any SDI related work? Is it planning any?

Are you involved in any SDI efforts?

Do you think the SDI is feasible?

Is it essential for the security of our nation?

With regards to the command and control issue, can you envision possibilities for AI?

Characteristics/Criteria. The literature review has revealed many areas to consider before embarking on a research and development path. An evaluation and analysis of these characteristics with respect to artificial intelligence and command and control will give an indication

of what path research in AI and C2 should take to be of most benefit to the SDI.

Degree of Risk. Many risks are associated with any research and development effort. These must be evaluated to help determine the feasibility, practicality, and usefulness of the system.

Development risk

Can the system be developed? (conditional on funds and the planned development time frame)

Technology risk--addresses the maturity of the technology involved

How successful have attempts at practical applications in AI been?

Data risk--addresses the availability of the information necessary to build a system

Will the high classification levels of command and control technology present a problem?

Are there any obstacles to obtaining and using AI data?

Development effort--involves the amount of effort, including people, time and funding resources, required to develop system applications

Is too much effort being placed on AI techniques?

Is the amount of effort forecasted for the SDI reasonable?

How much effort should be placed on AI?

Technical utility

How useful will the new command and control system be?

Is it worth the time, money , and effort that is being spent and is forecasted?

Generic Architecture. Two different aspects are addressed, one deals with the software structure and the other with how the command and control systems are linked together.

Are you familiar with different software structures?

Is a modular software concept the best choice?

Does the software allow for incorporation of new software without vast amounts of rewritten code?

Is a distributed architecture appropriate for the SDI?

Does it allow for interlinking with other research the DOD is currently working on?

Survivability. The issue of survivability is critical in two different ways. Survivable long-range communications are a must and a system must be survivable in a nuclear environment.

Can command and control systems be made "survivable"?

How critical is this characteristic?

Reliability. Command and control systems must function in peacetime as well as in combat situations.

Can AI systems be deemed reliable?

Are command and control systems reliable enough?

Will VHSIC technology increase the reliability of command and control systems enough?

Will protective shielding increase the reliability of command and control systems?

Do you see validation and verification of the program as a feasible task? How would it be done?

Data Processing. This refers to the gathering of huge quantities of raw data, filtering out the inappropriate data, and processing the rest. The SDI will require an enormous amount of data processing.

Do the capabilities to process huge amounts of data exist?

Can AI help in this area? How?

Flexibility. This addresses flexibility with respect to knowledge representation. An inference system must be capable of dealing with information that is common to the command and control domain. This means the inference system must be adaptable enough to work in or with the knowledge representation framework chosen for a task.

Can AI systems be flexible enough with respect to knowledge representation?

How far in the future before AI techniques are mature enough?

Adaptability. This pertains to meeting unpredictable threats quickly.

Can AI programs be adaptable enough? (react quickly enough)

Can AI aid command and control systems in this area? How?

Real-time response capability. A real-time response is essential for an effective command and control system. If it takes days to get a status report, it might be too late.

Are the data processing requirements that are predicted for the SDI too immense?

Can AI help filter data?

Can AI help shorten response time? How?

Do you expect AI to eliminate the "Man in the Loop"? (an automated system)

Complexity. Command and control systems tend to be very complex.

Can AI help simplify some aspects of the SDI?

Will using AI just add to the complexity of the whole system?

Implementation Language. Addresses the issue of what programming language will command and control systems use.

Is it feasible to use ADA? (DOD's standard software language)

Is it realistic? Is it cost-effective?

Can AI programs use ADA effectively and efficiently?

What about using other programming languages that are specifically designed for AI? (PROLOG, LISP)

Future Trends. By getting a feel for where AI is heading in the future it is easier to decide where to concentrate future research efforts.

What do you envision for AI in the future?

What techniques/applications will be most common?

What do you envision for command and control technology in the future?

Will AI be useful in command and control technology?

How soon before knowledge-based systems can aid command and control?

Conclusion. Thank the interviewee for his/her time.

Is there anything else you would like to add?

Do you have any questions that I can answer for you?

Any other comments or thoughts on AI, BM/C3 or the SDI?

Chapter Summary

The contents of this chapter established the methodology used to collect and analyze the research data. The methodology considered the following:

1. Collecting data on AI techniques and applications and researching command and control technology by means of:

    a. A literature review.

    b. A series of interviews.

2. Analyzing the data by:

    a. Identifying command and control technology that could benefit from the use of artificial intelligence.

b. Determining AI applicability to the SDI's Battle Management/Command, control and communications objective.

c. Comparing interview data and literature review data.

3. Critiquing the collective data for useful research endeavors that would be beneficial for the Strategic Defense Initiative.

4. Postulating the potential benefits of using AI in the SDI's BM/C3 program.

In summary, a well-established research methodology is a road map to successful research by telling us where we went and how we got there.

IV. Results

This chapter will present the results of the interview process for this thesis. Included are comparisons between the interview data and the literature review data, where appropriate. This chapter will follow the order of the interview guide.

Background

During the interview process, people from organizations throughout the Department of Defense were contacted. Organizations that were contacted include: Rome Air Development Center, Griffiss AFB NY; Office of the Secretary of Defense, SDI Office, Pentagon; Rocket Propulsion Lab, Edwards AFB CA; Jet Propulsion Lab, Pasadena CA; Space Division, Los Angeles CA; Electronic Systems Division, Hanscom AFB MA; Space Technology Center, Kirtland AFB NM; MITRE Labs, Bedford MA; Aeronautical Systems Division, Wright-Patterson AFB OH; and Air Force Institute of Technology, Wright-Patterson AFB OH. Some interviews were held over the telephone while other interviews (primarily those at the Rome Air Development Center) were done in person. Approximately forty interviews were held.

Most people that were interviewed had either engineering or computer science undergraduate degrees. Only one person had a degree in AI. Everyone had a bachelors

degree, several had masters degrees and a select few had doctorate degrees.

Although all the people contacted for interviews were known to be working in either the AI or BM/C3 area, most had difficulty describing an area of expertise. This may be due to the fact that most interviewees had worked in the AI or BM/C3 area for less than three years. Areas of expertise included: applications of AI into spacecraft, radiation hardened electronics, human factors, tactical warning, BM/C3, architectural concepts for the SDI, software, Artificial Intelligence, Battle Management and simulation models, expert systems and applications, image exploitation, data base management, and speech recognition.

One important aspect that became quite evident during the interview process was the lack of experience among the AI personnel interviewed. Only one person had a degree in AI and the others had no formal training in AI. Some had taken short courses in AI and the majority learned about AI and became familiar with it as they worked in that area. The Department of Defense will have to increase the number of AI experts in the future if they expect to utilize the new technology.

The Air Force has taken a step in the right direction by forming an AI Consortium (comprised of eight universities) dedicated to artificial intelligence development. The Rome Air Development Center at Griffiss

AFB has responsibility for the consortium. The goals are to improve the Air Force's AI research and development capability and to provide training for Air Force technicians and scientists.

Additionally, the Air Force Institute of Technology at Wright-Patterson AFB OH has developed graduate programs for masters and doctorate degrees in AI. Currently, 34 Masters and 2 PhD students are enrolled in the programs. AFIT has also created a five-week Professional Continuing Education (PCE) program in Artificial Intelligence. It is expected that 90 students will complete the course each year.

Artificial Intelligence

Almost everyone interviewed had been working with AI for less than three years. A few stated that they weren't familiar enough with the technology to be able to answer any questions about AI adequately.

The areas of AI that appear to be the most promising for the future are expert systems, knowledge-based systems, natural language processing, and automatic programming. These areas were mentioned most frequently by the interviewees. More specific applications are discussed later in the chapter.

There is some debate over user acceptance of AI. Some people stated that AI would never be totally accepted, while others said that, in time, it would be accepted.

One person predicted that it is just a matter of time before people accept AI. As the years pass, people will be exposed to AI concepts and ideas much earlier in life. Pilots will be trained on equipment which utilizes AI technology. Instead of trying to restructure their thought processes to accept AI, people will learn and accept the new AI technology as it progresses.

A few people interviewed had skeptical opinions about the field of artificial intelligence. One person said that AI may be "in vogue" now, but in a few years it would revert back to where it was a few years ago (out of the public interest). Another person said AI is just the next generation software and it was bound to happen eventually. Another noted that AI can only be used to the extent that it matures. And AI can never be error-free because it is mathematically impossible to test all combinations.

Although the above opinions may look upon AI negatively it is important to realize that AI limitations do exist. While many people believe that AI can and will solve all the problems of the future, this is not always the case. AI will be able to solve some problems, assist with others and be useless for still others.

Battle Management/Command, Control and Communications

It was easier locating people who had worked in the BM/C3 area than people in the AI area. Most people interviewed had worked in the BM/C3 area for three years or less.

A variety of topics were considered to be receiving a lot of attention in the command and control area. This may be due to realizing the continual need to strive for state-of-the-art technology so we can continue to maintain the "upper edge" against enemy threats.

Topics mentioned by interviewees included event classification, discrimination, data processing, system architecture, software structure, and positive control. All interviewees felt that AI could benefit command and control in all of these areas.

Event classification includes using sensors to collect data, analyzing the data, and classifying the event properly. An event could be anything that sensors detect such as a missile, a decoy or debris. Techniques in pattern recognition (perception) are expected to aid the target discrimination area. Discriminating among the debris, decoys and missiles is a key concept. The discrimination concept is heavily dependent on apriori information. But it is a realistic possibility that what will be seen in a war will be new. It will be the first time it is seen and there will be no apriori information available. Interviewees could envision an expert system assisting with the huge data processing problem, discriminating among various events, and thereby classifying an event quickly and efficiently. Expert systems that can efficiently search their knowledge bases will be very useful in these areas.

Most people interviewed agreed that an area requiring more research and development is in system architecture. There are many tradeoffs associated with either a distributed, centralized or hierarchical architectural concept. One study has just been initiated at Electronic Systems Division, Hanscom AFB to determine the best approach. Additionally, other contractual (and parallel) efforts have also started that essentially explore the same areas. One important aspect is to be sure that the command and control system can be linked with the weapon system, the surveillance system, and the battle management system.

Software structure was not mentioned as often as the other topics, but this may be due to the interviewees' areas of expertise. Only a couple worked in the software area. A critical issue that was mentioned concerned maintaining the truth and validity of the knowledge base. Areas in which AI could assist are in knowledge base maintenance, search techniques (to minimize time), and storage techniques.

Positive control was referred to in nearly all interviews. It refers to how much time is required to make a decision. Most critical is the need for a real-time response capability. For a BM/C3 system to be effective it must respond very quickly to enemy threats.

Natural language processing was mentioned by several interviewees as a potentially useful AI technique. A system that can automatically translate languages was thought to be

an aid to intelligence communications. But one person noted that speech recognition and delineation is extremely difficult and it will be many years in the future before the technology is mature enough.

Strategic Defense Initiative

All of the organizations contacted were currently doing work for the SDI. Some were doing in-house work but most were planning contractual efforts or already had contractual efforts started.

Comments varied widely on the feasibility of the SDI. Most declined to answer stating that it was still a research and development program. Some people said that too much time, money and effort was being invested in the program, and because of that the program will never survive. Others said that the concept of the SDI is possible as soon as the technology develops enough, and it may be many years (20, 30 or even 50) in the future. Most agreed that it was essential to be doing something that would help the nation maintain a credible level of deterrence against the Soviet threat.

Most interviewees agreed that it was inevitable that AI would be used in the SDI. The SDI is a defensive system and as such a quick system is essential. The time available to detect an enemy missile is very short. It is expected that AI can be useful in the event discrimination and classification areas by processing information rapidly.

Since the United States has a limited arsenal it becomes very important to only shoot at things that are lethal. AI can also assist in assigning weapons to targets (target allocation) and assigning sensors to objects (resource allocation).

Another area in which AI technology would be useful is satellite maintenance. One effort on contract at Rome Air Development Center, Griffiss AFB uses an expert system capability in satellite health systems. Their job would be to repair and take over failed satellites. Another related area in which AI technology should be explored is in increasing the survivability of satellites. If ground facilities are lost the satellites in space would not be able to function for long.

Characteristics/Criteria

It became evident during the interview process that the AI applications to command and control found to be useful for the SDI were not developed nor mature enough to actually assign characteristics or criteria to them for evaluation. For instance, it is impossible to determine if an expert system is more reliable than an automatic programming technique. However, using the criteria developed in the research methodology, an evaluation and analysis of these characteristics with respect to artificial intelligence and command and control will give an indication of what path research in artificial intelligence and command and control should take to be of most benefit to the SDI.

Risk. The development risk of a system like the SDI is extremely high. Most people thought that it was feasible as long as the money was available. Others said that even though the risk was high the system "has to be developed". It is necessary for the defense of our nation. Some differences existed among the estimates of time required to develop such a system. They ranged from at least twenty years in the future to fifty years.

There have been attempts at practical applications of AI technology to the SDI issue. Programs that simulate actual battle environments include KNOBS (a tactical mission planning tool) and SWIRL (an air battle simulator). They both use knowledge based expert systems. These simulations are very important because they help people understand the problem better. In that aspect alone, AI is very useful. Once the problem and solution is defined then it is possible that non-AI techniques can be used to solve the problem.

The high classification levels required for command and control do not appear to present a problem. An AI system for command and control and the SDI would most likely be used on a secure system or in a vault.

The major obstacles mentioned by interviewees concerning AI were the maturity of AI technology, the limitations of AI, and the user acceptance of AI.

Most interviewees said that a system like the SDI would certainly be useful. But questions are still raised as to

the reasonableness of the time, money and effort bing invested in the SDI.

Generic Architecture. Most people interviewed agreed that a distributed system was appropriate for the SDI. It was also important to be able to link various systems together. However, no one could say with any degree of certainty what type of architecture was the best--distributed, hierarchical or centralized. Many contracts have already started to try and determine the best approach for the SDI.

Software structure was another area that interviewees thought needed more research and development work. A new generation of software is essential in order to obtain the speed that is required for command and control systems. One person predicted that the number of lines of code that would have to be generated for a BM/C3 system would be so large that an expert system would be needed to help generate the software. Automatic programming techniques would certainly be useful in this area.

Survivability. It was agreed by interviewees knowledgeable in BM/C3 that command and control systems must be survivable. But, at the same time, they admitted that no system can be completely "hardened". Exposure to blast and radiation make it almost impossible to completely protect such a system. One person noted that it would only take exposure to one electromagnetic pulse (EMP) and all the

software in a system could be lost. The SDI requires a radiation hardened, reliable and survivable system.

Reliability. It is very hard to determine if AI systems can be deemed reliable. A few people mentioned the impossibility of testing an expert system. There are so many possible combinations that it is mathematically impossible to test all of them. There is "no room for error" in the software but it is impossible to check.

VHSIC technology will allow for faster, more relible systems. As the integrated circuits become smaller, the amount of protective shielding required decreases and the cost is lower. The advancement in this area can aid AI hardware.

Verification and validation of a BM/C3 system is another significant problem. It should be pointed out that a program can always be verified since that suggests a quantifiable performance on defined problems. However, no one knows how to validate AI software or even non-AI software. One person said it would take 10,000 lines of code to test just one process. And it is conceivable there would be thousands of processes with such a system. Here again, automatic programming techniques could assist in generating the code to test various processes. Another person said that all the components of such a system would have to be tested on the ground. In this case it could be twenty to fifty years in the future before it would be

operational. One person said the only way to test such a system would be to "fly it". This is very risky, but AI programs could be embedded in the system to periodically test the system and only report when failures occur. Another possibility is to use knowledge-based simulators to "fly" the system. This appears to be more realistic and practical.

Data Processing. The capabilities to process large amounts of data do currently exist. But, the big issue with the SDI is the time that is available to process the data. Only minutes will be available to detect a missile after it has been launched. One person gave an example of the computational capabilities that would be required to process one small sector of data. He said it would require two to five Symbolics (the fastest LISP machine today) machines number crunching eight hours a day just to keep up with the data. A few people mentioned that parallel processing would be essential in order to process the data fast enough.

Flexibility. Most people knowledgeable in the AI area agreed that flexibility was critical in terms of decision making processes. Decision support systems are being developed to assist commanders in BM/C3. These systems are not exclusive of AI. Some aids include rule-based expert systems.

Adaptability. Interviewees were sure that AI programs would be able to react quicky enough. That is one reason why

people are looking to AI for solutions to some of their software problems. AI is faster and more efficient at performing certain tasks. AI can aid command and control by being able to meet the short reaction times mandated by incoming ballistic missiles.

Real-time Response Capability. This is a critical requirement for a BM/C3 system for the SDI. Experts in AI are certain that AI will be able to help in this area in the future. Expert systems are expected to assist in filtering data, classifying data and discriminating among decoys, debris, and real targets. They may also assign weapons to targets (target allocation) and assign sensors to objects (resource allocation).

The issue of the "Man in the Loop" generated a lot of discussion during the interviews. Some people said that in order for a system to have a real-time response capability it has to be autonomous (no man in the loop). There is so little time available that a human would not be able to make a decision.

Others said that there would have to be a man in the loop or the public would never accept such a system. One person said that the SDI would have to officially report that there will be humans in the loop but realistically there would be no humans in the loop.

The majority of interviewees pointed out that there were two different situations that had to be considered--

crisis and peacetime. In a crisis situation, timelines are so short that it would have to be an autonomous system. In this case a knowledge-based expert system would take over the decision-making process. A human would only be available for override capabilities. As one person said, "keep him in the loop but out of the way". In peacetime, it was a little safer to have a man in the loop but there would still have to be a certain amount of autonomous operation.

Complexity. Command and control systems are very complex and will continue to remain that way. AI will not simplify certain aspects of the SDI but it can benefit the SDI by improving various components of a BM/C3 system.

Implementation Language. None of the people interviewed stated that any particular programming language should be used for AI. Most work in AI is done in LISP today. Certain programming languages have been designed specifically for AI and are therefore more efficient for AI than other conventional programming languages.

Nobody interviewed was doing any work in ADA, the Department of Defense's standard software language. Most said that ADA was not realistic or cost effective for AI.

One person said that by the time companies begin doing extensive development in the field that the standard (ADA) would already be outdated. A standard is needed but it may be more limiting than helpful. Another person countered this opinion by stating that Fortran was developed years ago and is still being used today (it is not obsolete).

Future Trends

The entire SDI system is a long ways in the future, but smaller components of the system can be developed and used sooner. One person said command and control is the "glue" that holds the entire system together. It is the most complex and the most critical of all the SDI. It is inevitable that AI will be used in the BM/C3 objective of the SDI.

AI will play a big role in the command and control area because of the timelines and the decision making requirements. Expert systems, knowledge-based systems, natural language processing, and automatic programming will all be beneficial to the SDI. Right now, a lot of people are working in AI but not many have hardware. They are all paper centers. AI is just beginning to get into the application area. Many contracts are currently underway to help advance this technology. But it will still be a few years in the future before the technology is mature enough.

Chapter Summary

This chapter presented the results of the interview process. The results are a collection of opinions and comments from various people in the AI and BM/C3 areas.

It was generally agreed that AI technology would be used and be of benefit to the BM/C3 objective of the SDI. Primarily the same few applications of AI came up again and

again in the interviews--expert systems, knowledge-based systems, natural language processing and automatic programming. All of these have potential in the future.

V. Conclusions and Recommendations

This fifth and final chapter summarizes the main points and conclusions of this thesis. It endeavors to present inferences and recommendations warranted by the nature and depth of the research. Also included are recommendations for the DOD in future AI system acquisitions.

Main Issue

The main result of this research effort is that it is inevitable that AI will be used and be of benefit to the BM/C3 objective of the Strategic Defense Initiative. It is just a matter of time until research in AI and BM/C3 have matured enough. But there is evidence that certain aspects of BM/C3 will require AI technology. If research is directed in these areas then perhaps the technology will be available sooner.

Artificial Intelligence techniques that were found to be most useful and have the most promise for the future in the BM/C3 objective of the SDI are: expert systems, knowledge-based systems, automatic programming and natural language processing.

Expert systems were found to be useful because of the speed with which they can process data. They can search their knowledge data bases very quickly and obtain answers and decisions much faster than humans can. This was found to be useful in the event discrimination and classification

aspect of the BM/C3 issue. They can also be used in the sensor allocation and resource allocation areas.

Knowledge-based systems are often thought to be synonymous with expert systems. Extensive data bases are required for both these AI techniques. They can benefit the BM/C3 issue in satellite maintenance, automatic testing of systems, decision-making, and pattern recognition. Some simulation programs already exist that use expert system capabilities as a tactical mission planning tool and as an air battle simulator. Decision support systems usually include a rule-based expert system.

Automatic programming techniques are expected to aid the BM/C3 issue by helping to generate the massive amounts of programming code that will be required for such a system. Not only does the system itself require huge programs but testing of various components of the system will also require much software.

Natural language processing could be useful in speech recognition areas. A program that can translate into different languages would be an aid to intelligence communications. But this application of AI is not thought to be as promising or as beneficial to the SDI as the previously mentioned applications of AI. Part of the reason is the extreme difficulty of getting a machine to understand natural language.

Conclusions

Potential applications of using emerging AI technology in the SDI's BM/C3 objective include the following.

1. Sensor resource allocation for determining when to use available sensors in order to obtain the most timely and valuable information.
2. Target allocation for assigning weapons to targets.
3. Mission planning for a variety of strategic and tactical applications.
4. Battle tactics and plan evaluation/simulation.
5. Targeting, including nominating targets, prioritizing targets and weaponeering.
6. Near real-time situation assessment, of both own forces and enemy forces.
7. Sensor data-processing.
8. Information retrieval efficiently and quickly from knowledge bases.
9. Decision support systems.
10. Surveillance and Intelligence (i.e. sensor analysis, pattern recognition).
11. Discrimination among decoys, debris and true targets.
12. Electronic equipment maintenance (i.e. satellites that repair themselves).

13. Software generation for BM/C3 systems and for the testing of such systems (i.e. automatic programming).

14. Increase the testability of systems (use AI to periodically test systems and only report when failures occur).

The potential benefits of using AI technology in the BM/C3 objective of the SDI are fairly straightforward. AI techniques make better use of knowledge representation and therefore are more efficient and faster than any other computer programs. AI techniques will allow the SDI to develop the real-time response capability that is essential for a defensive system.

Recommendations

The interview process used in this research indicated that the DOD may be lacking the cadre of operational and technical people needed to explore new ways of using AI in command and control. To effectively apply AI, the DOD must educate a cadre of personnel on technological capabilities. The DOD should inform key personnel about AI's potential and limitations. It should select a specific problem to which AI technology could be applied and encourage contractor(s) development of a demonstration program (no cost or commitment to DOD). Then apply the system in a controlled (measurable) environment to test performance versus conventional methods. Only by following a path of educating people, selecting a problem, developing a demonstration

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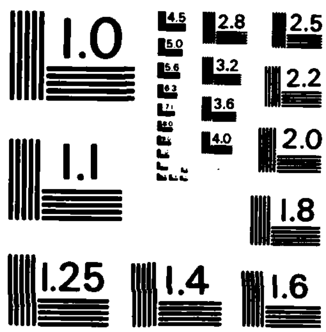

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program and testing it in a controlled environment can AI technology be used and accepted.

The Air Force Institute of Technology at Wright-Patterson AFB OH would be an ideal place for applying AI technology. Graduate students in the School of Engineering often build prototype expert systems for thesis or dissertation research. By allowing the students to remain at AFIT several months after graduation they could further refine their systems. They may eventually be able to test and compare the expert system's performance with conventional methods. The expertise and knowledge of these AI students should be utilized as much as possible.

It is essential that command centers remain current of the advances in AI processing. Recommendations for the next 5-10 years are to continue to create and encourage development groups in industry and military labs, and encourage increased contact between such groups and university and industrial basic research laboratories. Periodic briefings and visits to universities and research and development companies will help ensure that systems acquired for near and intermediate terms will be compatible with the transition to AI systems.

Appendix A

Interview Guide

Background.

What is your name? Organization?

What is your position/job title?

What is your education level? (M.S., B.S.)

What is your area of expertise?

Artificial Intelligence.

Are you familiar with AI?

Have you worked in the AI area?

What areas of AI do you feel hold the most promise for the future?

- -natural language processing
- -intelligent retrieval from data bases
- -expert consulting systems
- -theorem proving
- -robotics
- -automatic programming
- -perception
- -expert systems
- -knowledge-based systems

Is there enough user acceptance of AI?

Battle Management/Command, Control and Communications.

Are you familiar with command and control?

Have you worked in this area?

What areas of command and control are getting the most attention today? (only unclassified topics)

Do you think AI could benefit command and control? How?

Areas of concern in BM/C3:

-system architecture

-software structure

-data processing

Could AI help in these areas? Explain?

<u>Strategic Defense Initiative</u>.

Is your organization doing any SDI related work? Is it planning any?

Are you involved in any SDI efforts?

Do you think the SDI is feasible?

Is it essential for the security of our nation?

With regards to the command and control issue, can you envision possibilities for AI?

<u>Characteristics/Criteria</u>.

<u>Degree of Risk</u>.

Development risk

Can the system be developed? (conditional on funds and the planned development time frame)

Technology risk

How successful have attempts at practical applications in AI been?

Data risk

Will the high classification levels of command and control technology present a problem?

Are there any obstacles to obtaining and using AI data?

Development effort

Is too much effort being placed on AI techniques?

Is the amount of effort forecasted for the SDI reasonable?

How much effort should be placed on AI?

Technical utility

How useful will the new command and control system be?

Is it worth the time, money , and effort that is being spent and is forecasted?

<u>Generic Architecture</u>.

Are you familiar with different software structures?

Is a modular software concept the best choice?

Does the software allow for incorporation of new software without vast amounts of rewritten code?

Is a distributed architecture appropriate for the SDI?

Does it allow for interlinking with other research the DOD is currently working on?

<u>Survivability</u>.

Can command and control systems be made "survivable"?

How critical is this characteristic?

Reliability.

Can AI systems be deemed reliable?

Are command and control systems reliable enough?

Will VHSIC technology increase the reliability of command and control systems enough?

Will protective shielding increase the reliability of command and control systems?

Do you see validation and verification of the program as a feasible task? How would it be done?

Data Processing.

Do the capabilities to process huge amounts of data exist?

Can AI help in this area? How?

Flexibility.

Can AI systems be flexible enough with respect to knowledge representation?

How far in the future before AI techniques are mature enough?

Adaptability.

Can AI programs be adaptable enough? (react quickly enough)

Can AI aid command and control systems in this area? How?

Real-time response capability.

Are the data processing requirements that are predicted for the SDI too immense?

Can AI help filter data?

Can AI help shorten response time? How?

Do you expect AI to eliminate the "Man in the Loop"? (an automated system)

Complexity.

Can AI help simplify some aspects of the SDI?

Will using AI just add to the complexity of the whole system?

Implementation Language.

Is it feasible to use ADA? (DOD's standard software language)

Is it realistic? Is it cost-effective?

Can AI programs use ADA effectively and efficiently?

What about using other programming languages that are specifically designed for AI? (PROLOG, LISP)

Future Trends.

What do you envision for AI in the future?

What techniques/applications will be most common?

What do you envision for command and control technology in the future?

Will AI be useful in command and control technology?

How soon before knowledge-based systems can aid command and control?

Conclusion.

Is there anything else you would like to add?

Do you have any questions that I can answer for you?

Any other comments or thoughts on AI, BM/C3 or the SDI?

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This investigation determined the applicability of various artificial intelligence techniques to the Battle Management/ Command, control and communications (BM/C3) objective of the Strategic Defense Initiative.

This analysis was accomplished by an extensive literature review followed by personal interviews with members of various organizations within the Department of Defense. The results obtained are an accumulation of opinions and perceptions and are not to be taken as concrete facts.

Results indicated that the artificial intelligence techniques that would be most beneficial to the Battle Mnagement/Command, control and communications issue are expert systems, knowledge-based systems, automatic programming, and natural language processing. Areas of BM/C3 where these techniques were considered to be of most benefit include event classification and discrimination, resource allocation, sensor allocation, real-time response capability, data processing, surveillance and intelligence, electronic equipment maintenance, software generation and increased testability of BM/C3 systems.

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